

# SOIL NUTRIENT DEPLETION AND THE COLLAPSE OF RAPA NUI SOCIETY<sup>1</sup>

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Rapa Nui (Easter Island) is often depicted as a microcosm for world ecosystem disaster (Diamond 2004; Kirch 2004; Flenley and Bahn 2002). The island is thought to have been settled around AD 700 and by ca. AD 1150 the population had risen to the point where descent groups were defining territorial units focused around spectacular ceremonial platforms and statues (Kirch 1984; Skjølsvold 1994; Stevenson 2002). Pollen changes have been interpreted as evidence for deforestation as early as AD 750, and between AD 950 and AD 1400 it is thought that virtually the entire island was cleared as a result of widespread agricultural development to meet the demands of increasingly competitive chiefdoms (Flenley and Bahn 2002). Some researchers suggest that this deforestation led to massive physical erosion and extreme environmental degradation (see for example Diamond 2004; Flenley and Bahn 2002; Kirch 1984, 2000, 2004; Mieth and Bork 2004; Rolett and Diamond 2004). As a result,

it has been proposed that Rapa Nui society collapsed around AD 1500, and at European contact in 1722 it was depicted as anarchic with intense intertribal warfare (Kirch 2000:273; Van Tilburg 1994).

Recently the causes and extent of societal collapse have been questioned. McCall (1993), Hunter-Anderson (1998), and Orliac and Orliac (1998) maintain there is little evidence for massive physical erosion, and as an alternative, suggest that societal collapse might have been due to climatic change, with major droughts causing crop failure, famine, and warfare. Rainbird (2002) rejects environmental factors and suggests that societal collapse resulted from the introduction of European diseases. While we are not in a position to fully evaluate these alternatives, we have recently initiated a research program that investigates an additional factor, the role that soil nutrient depletion may have played in the process of societal transformation. Instead of focusing on physical ero-

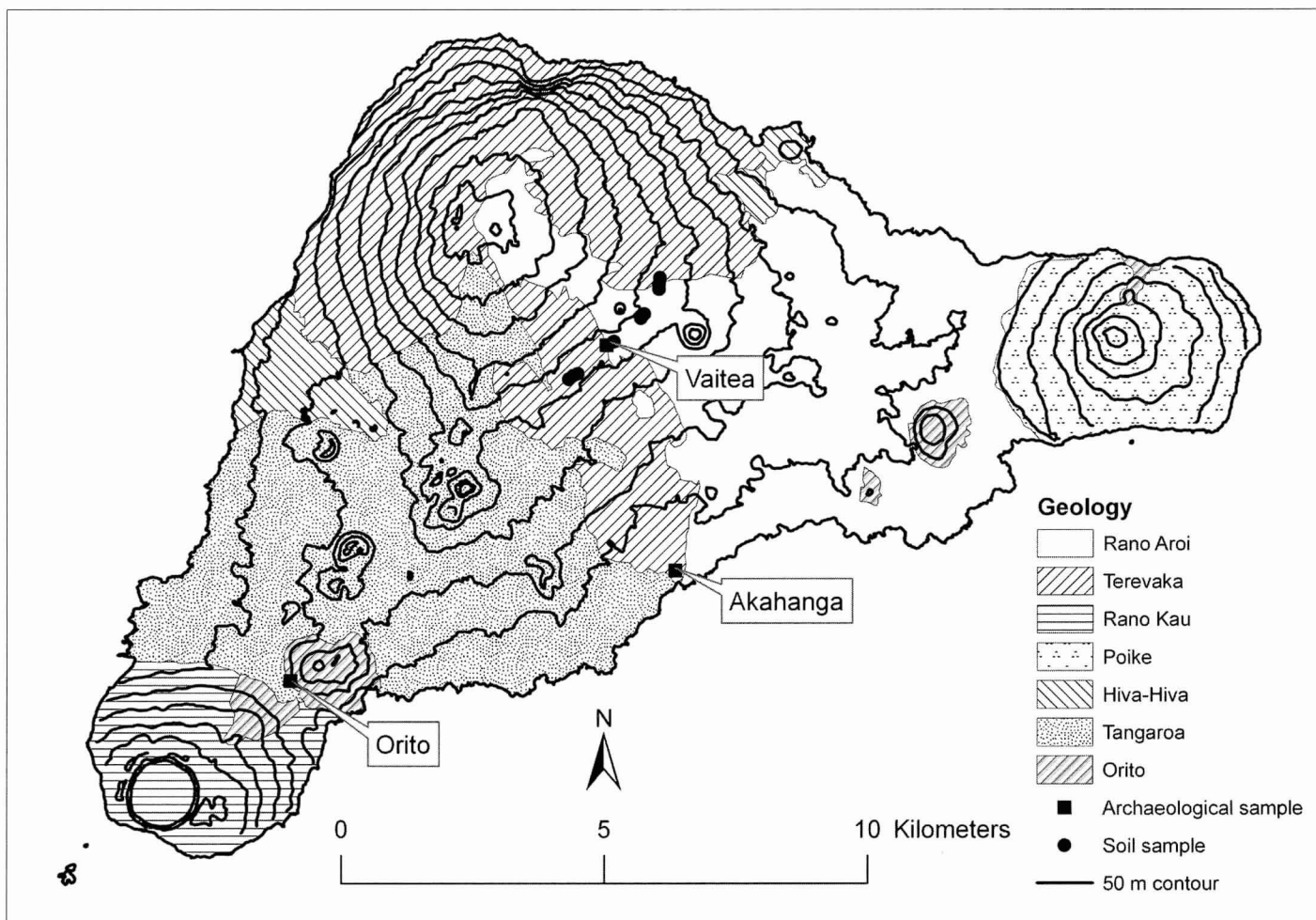


Figure 1. The geology of Rapa Nui. (after González-Ferrán et al. 2004).

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sion, we suggest that the poor and declining nutrient levels of Rapa Nui soils might have spurred unique agricultural adaptations and possibly contributed to dramatic societal change. In the following, we present some of our initial results and briefly outline our research program for evaluating the role of soil nutrient depletion in the collapse of pre-contact Rapa Nui society.

## RAPA NUI SOCIETY AND ENVIRONMENT

Rapa Nui is a small (166 km<sup>2</sup>) isolated volcanic island with moderate annual rainfall (ca. 1250 to 2500 mm). It consists of three main volcanoes, Terevaka (510 m), Poike (460 m), and Rano Kau (300 m), with many smaller cones (Figure 1). González-Ferrán et al. (2004) propose that the Poike flows began as early as 3000 kya, although Hasse et al. (1997) maintain that they are younger and date to ca. 500 kya. González-Ferrán et al. (2004) propose the Rano Kau flows date to ca. 2500 kya, the Terevaka flows to 1900 to 300 kya, and the Orito volcanics of the Rano Kau group to ca. 230 to 180 kya. The slopes of Terevaka are covered by Tangaroa flows that date to ca. 220 kya,

and the younger Rano Aroi flows. The most recent volcanic activity dates to ca. 10 kya and consists of the Hiva-Hiva flows. Flenley and Bahn (2002:15-16, emphasis added) suggest that "Easter Island rocks have slowly weathered to give a variety of reddish or brownish clay soils that are potentially quite fertile..." and "...the soils are best developed on the oldest rocks (Poike) and least so on the youngest (Terevaka). The variation in erosion of basalt means that soil is sparse in some areas but abundant and fertile in others." It is the differential fertility levels of the various volcanic substrates that we are interested in. Whereas Flenley and Bahn (2002) equate soil development with fertility, recent work in Hawai'i (Chadwick et al. 1999; Chadwick et al. 2003; Vitousek et al. 2004) suggests that this is a more complex relationship.

The culture history of Rapa Nui is reasonably well known although there is considerable disagreement about the timing of certain events and processes such as settlement and later societal transformations (compare for example the chronology presented by Flenley and Bahn 2002 with that presented by Kirch 2000). However, Flenley and Bahn (2002) and others (Diamond 2004; Kirch 2004, 2000, 1984; Mieth and Bork 2004; Rolett and Diamond 2004) do present a model for societal change based on ecological disaster. In its simplest form the model suggests that unrestrained population growth led to the overexploitation of seabird resources and the clearance of native vegetation for crops. The introduction of Polynesian rats (*Rattus exulans*) and their eating of seeds would have inhibited regeneration of the native

vegetation. The overall deforestation removed roots that held the soil and removed above ground plant matter that broke the force of raindrops and hence contributed to extensive physical erosion and a subsequent decline in soil fertility. The deterioration of the environment resulted in "...general famine, warfare, and collapse of the whole economy..." (Flenley and Bahn 2002:200).

The fundamental premise of this model is that extensive physical erosion has occurred throughout the island. We, however, note that the actual evidence of physical erosion on Rapa Nui is somewhat limited, for the most part being restricted to the older volcanic Poike flows and the margins of the steeply sloping cinder and ash cones (Mieth and Bork 2003; Mieth et al. 2002; Stevenson et al. n.d.). It appears that researchers have documented this dramatic, yet spatially limited physical erosion, and extrapolated it to the rest of the island. In a nuanced version of the ecosystem disaster model, Diamond (2004) describes Rapa Nui as "...a society that destroyed itself by overexploiting its own resources". Like Flenley and Bahn (2002) and others, Diamond (2004) focuses primarily on deforestation and physical erosion as the mechanisms of environmental degradation, but he does note the role that declining soil fertility and nutrient dynamics could have played.

In tropical regions phosphorus (P) availability often limits the productivity of agricultural systems (Louwagie 2003; Langohr and Louwagie 2002; Vitousek 2004; Vitousek et al. 2004).

There are various means of measuring P, including measures of the total quantity of P within soils, measures of chemical fractions of P, and indices of available P (e.g., resin-extraction; Mehlich 2 extraction) (Tiessen and Mohr 1993). Potentially available P can be added to soils via the dissolution of P-containing primary mineral, through aerial deposition of dusts from distant sources (such as Asian loess) and by human activities such as vegetative mulching and fertilizing. P is lost from soils through rainwater leaching, erosion of P-enriched surface soils, and the extraction of nutrients by horticultural and agricultural activities.

Recent research in the ca. 20 km by 3 km Kohala dryland field-system in Hawai'i demonstrates that pre-contact Hawaiians were exploiting a natural "phosphorus sweet spot" for the intensive production of large quantities of sweet potato (*Ipomoea batatas*) and other crops (Vitousek et al. 2004; Ladefoged and Graves 2005; see also Ladefoged et al. 2003 and Ladefoged and Graves 2000). In Kohala, the 60 km<sup>2</sup> field-system is limited on the upslope and downslope boundaries by precipitation levels. On the upslope side, rainfall (in excess of ca. 1900 mm year) has leached the nutrients from the soils, whereas on the downslope side lack of rainfall has inhibited conversion of P in rock to biologically available

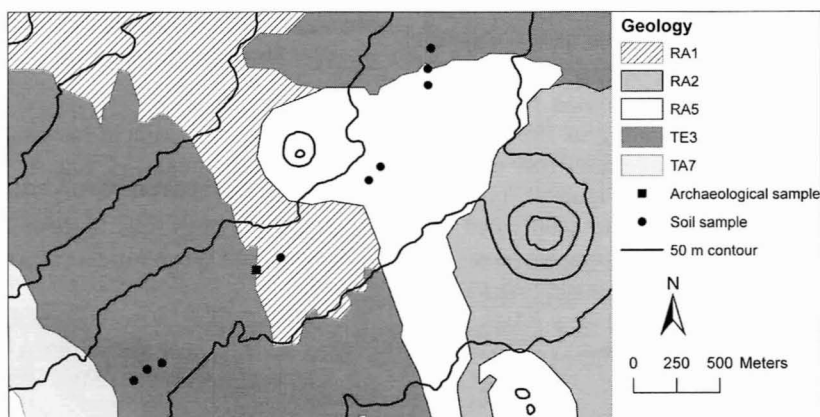


Figure 2. Geology of the inland Vaitea area.

P. In addition to the effect that rainfall can have on soil nutrient dynamics, the age of a geologic substrate is extremely influential because P is lost from terrestrial ecosystems over time. Ongoing loss of P means that on older substrates P has been depleted at lower rainfall levels than on younger substrates. Thus the rainfall zone in which a nutrient hotspot can be maintained narrows with increasing substrate age. Contrary to the suggestions of Flenley and Bahn (2002:15-16), after a certain point (generally a few thousand years) it is the younger substrates that will contain higher levels of P and be more fertile, not the more “developed soils” on older flows. In Kohala, the agricultural “sweet spot” is defined by soils with a resin-extractable P level of greater than ca. 25  $\mu\text{g/g}$  (Vitousek et al. 2004). It should be noted, however, that Burtenshaw et al. (2001) suggest that different varieties of sweet potato can flourish under varying soil nutrient conditions.

#### INITIAL ANALYSIS OF RAPA NUI SOIL NUTRIENT LEVELS

We have begun to assess soil nutrient levels on Rapa Nui by collecting and analyzing soil samples from nine geologic sample points in the upland region of Vaitea, and samples from three archaeological contexts throughout the island (Vaitea, Orito, and Akahanga) (see Figure 1). In Vaitea the nine soil samples were taken along a transect that crossed two major volcanic flows; the Terevaka volcanics dating to 1800 kya to 300 kya, and the younger Rano Aroi volcanics that date to sometime after ca. 180 kya. As shown in Figure 2, both of these major volcanic groups have been further subdivided by González-Ferrán et al. (2004). Our sampling transect began in the west on the Terevaka TE3 flow and extended eastward crossing onto a Rano Aroi RA1 flow, then onto a Rano Aroi RA5 flow, and then finally back onto a Terevaka TE3 flow. This area is currently used for low intensity ranching, and there is no evidence that the soil properties have been significantly modified during the historic era. Our initial hypothesis was that the nutrient levels of these three different substrates should differ, with the older Terevaka TE3 flow having lower

nutrient levels than the younger Rano Aroi RA1 or Rano Aroi RA5 flows. We were also interested in whether it was possible to distinguish nutrient levels on the two Rano Aroi flows, which presumably date to different times, although the precise chronology of these flows is unknown. The sample points along the transect were intentionally taken at approximately the same elevation. This was done to minimize rainfall vari-



Figure 3. “Boulder garden” in the Vaitea area.

ability at the nine sample locations. As noted by Vitousek et al. (2004) the amount of rain at a location can significantly affect soil nutrient levels via leaching and biological processes. Our strategy was to collect soil samples from a relatively constant elevation to reduce orthographic rainfall variability.

Soil samples were collected at 20 cm to 25 cm below ground surface, just above the A – B soil horizon boundary. All soil samples were sieved and divided. One sub-sample

Table 1. Chemical characterizations of Rapa Nui soils.

Sample	Geologic substrate	Si/Nb	Ca/Nb	P/Nb	P	resin-P
G-1	Terevaka 3	661	9	65	0.4844	3.98
G-2	Terevaka 3	443	19	65	0.6197	1.89
G-3	Terevaka 3	598	15	67	0.4975	1.83
G-4	Rano Aroi 1	209	2	34	0.3186	1.34
G-5	Rano Aroi 5	738	39	79	0.5717	2.20
G-6	Rano Aroi 5	881	96	92	0.6285	2.49
G-7	Rano Aroi 5	340	16	65	0.5281	1.26
G-8	Terevaka 3	160	7	56	0.5063	1.77
G-9	Terevaka 3	806	27	46	0.3448	1.98
A (Aka- hanga)	Terevaka 1	1219	76	85	0.7245	149.00
A (Vaitea)	Rano Aroi 1	1400	57	71	0.3972	1.75



Figure 4. Akahanga “veneer garden”

was analyzed for resin-extractable P and for total C and N at Stanford University. Resin P was determined following the method of Kuo (1996), with the addition of cation exchange resin to reduce cation concentrations in solution. Total C and N were analyzed on a Carlo Erba CN analyzer. A second sub-sample was analyzed for pH (1:1 water) as well as exchangeable cations and cation exchange capacity (CEC) at the University of California, Santa Barbara, using a modification of the  $\text{NH}_4\text{OAc}$  method at pH 7.0 (as specified by Lavkulich (1981).



The resin-P values of the nine sample points are shown in Table 1. These values are notable for their low levels. There is no marked pattern in variability between the differ-

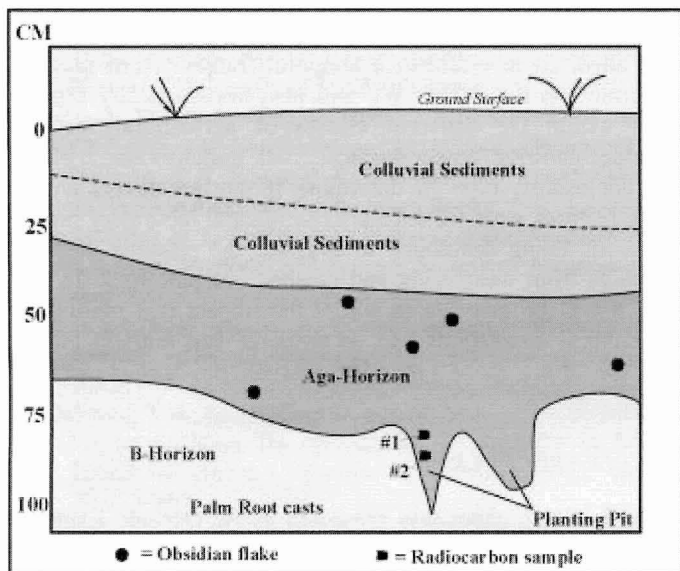


Figure 5. Orito profile showing location of radiocarbon samples (from Stevenson et al. n.d.).

ent flows, with all flows having resin-P values well below the “sweet spot” value for growing sweet potato of greater than 25  $\mu\text{g/g}$  established by work in Kohala, Hawai‘i.

An additional soil sample was taken at 20 cm to 25 cm bgs in an archaeological “boulder garden” in the Vaitea area. Stevenson et al. (2002, 2005) document various Rapa Nui agricultural adaptations, including “boulder gardens” (areas where 5 cm to 80 cm rocks have been stacked to form rough wind breaks; Figure 3); “veneer surfaces” (areas with 5 cm to 20 cm rocks placed on the ground surface); “lithic mulched gardens” (areas where 2 cm to 20 cm diameter rocks have been worked into the upper soil horizon); planting depressions (1 m to 2 m diameter pits dug 30 cm to 40 cm into the substrate, often filled with rock, referred to as a *pu*); and planting enclosures (dry-masonry rock walls built to form windbreaks, referred to as *manavai*). The resin-P value of the soil sample from the “boulder garden” on a Rano Aroi RA1 flow was of a similarly low level to the 9 other soil samples taken in Vaitea area. These results would suggest that even the younger volcanic substrates of the interior of Rapa Nui have been leached of their nutrients and would have been a relatively poor horticultural environment during the prehistoric period.

Two additional coastal archaeological locations enhance our understanding of soil nutrient levels. Recent bulldozer disturbance at the southwest base of Maunga Orito has exposed a 100 m long soil profile (Stevenson et al. n.d.) (see Figure 1). The profile contains a variety of archaeological features including cooking hearths, storage pits, mixed agri-

cultural layers, planting pits, and agricultural veneer surfaces. The archaeological remains are on an Orito volcanic flow that dates 230 kya to 180 kya. Stevenson et al. (n.d.) report the details of the site and the chronology for various residential and agricultural activities, but here we note the results of soil nutrient analysis from Section D of the profile (Figure 5). This is an area that contains a mixed agricultural horizon, without any rock mulching or veneer surfaces. Two radiocarbon dates on charcoal from a planting pit extending down from the agricultural horizon establish the use of the agricultural zone sometime in the 15<sup>th</sup> century (BP 450+/-40, two-sigma Cal AD 1430-1490; BP 460+/-40, two-sigma Cal AD 1410-1480). This is relatively early in the culture history of the island, and it is significant that no rock-based agricultural techniques are present. Phosphorus analysis using the Mehlich 2 extraction method of 6 soil samples from pits extending below the agricultural horizon produced values that range from 15 to 26  $\mu\text{g/g}$ . The Mehlich 2 extraction method differs from the resin-P extraction method in that it is a bit more invasive, and thus produces values that are relatively higher in relation to the resin-P extraction method. The Mehlich 2 values of 15 to 26  $\mu\text{g/g}$  are thus still below the resin-P extraction method “sweet spot” value of greater than 25  $\mu\text{g/g}$ . Again it looks as if people were growing crops in relatively nutrient poor soils.

A final soil sample was collected from a “veneer garden” archaeological site at the coastal location of Akahanga on a Terevaka TE1 flow (see Figure 1 and Figure 4). This is

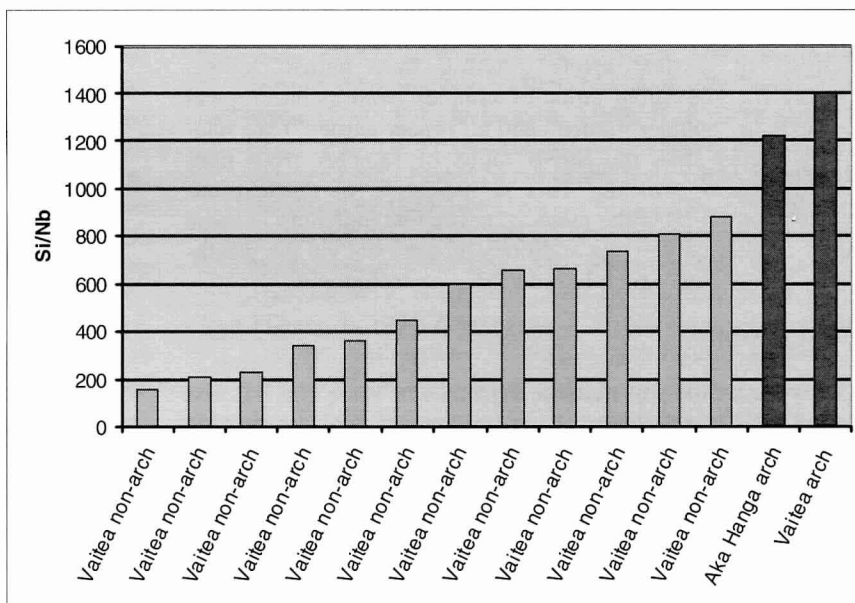


Figure 6: Si/Nb ratios for archaeological and non-archaeological soil samples.

the site of an elaborate prehistoric elite village that contains large residential structures (*hare paenga*), religious platforms (*ahu*), and statues (*moai*). The veneer garden is located approximately 250 meters from the coast and just inland from the elite village. The soil sample was taken at a depth of 20 cm bgs, underneath a layer of 5 cm to 15 cm rocks that had been placed on the surface. The resin-P value from the sample is extremely high (149  $\mu\text{g/g}$ ), and could be the result of a number of non-mutually exclusive processes. The first alter-

native is that the creation of the rock veneer surface enhanced the nutrient level of the underlying soil by the slow weathering of the surface rock and incorporation of nutrient-enhancing rock particles into the underlying soil. While we cannot evaluate the feasibility of this alternative at this point, we are currently developing lab procedures to do so. Alternatively, the high resin-P value might reflect vegetative mulching or composting of the garden during the prehistoric period. Finally, we cannot rule out that the high resin-P value is the result of recent historic activity (such as the application of modern fertilizers) in the area, as there are currently remnant taro (*Colocasia esculenta*) plants growing in the "veneer garden".

One means of documenting changing soil nutrient levels is to establish the ratio of silicon to niobium (Si/Nb) for samples taken from deep trenches that extend from the ground surface to bedrock. This procedure is based on the premise that silicon is a mobile element, whereas niobium is not. The relative difference between the Si/Nb ratio of a near-surface sample and the Si/Nb ratio of an underlying parent material sample will indicate whether soil nutrients at the surface have been enhanced, remained stable, or have been depleted. Relatively higher Si/Nb values at the surface in relation to the underlying parent material can indicate minimal nutrient depletions in areas without cultural modifications (i.e., "natural" areas), or alternatively nutrient enhancement in areas with "cultural" archaeological modifications. Unfortunately, we do not currently have stratified samples from deep trenches, but we have analyzed the subsurface (20 cm to 25 cm bgs) samples from Vaitea and Akahanga and these possibly suggest changes in nutrient levels resulting from human actions (Figure 6). The Si/Nb ratios of samples from archaeological contexts (a "boulder garden" and a "veneer garden") are relatively higher than the Si/Nb ratios of samples from non-archaeological contexts. This is indicative of nutrient enhancement, possibly the result of vegetative mulching in these areas or alternatively the additions of nutrients via the weathering of innovative rock-based gardening techniques.

## CONCLUSIONS

Our work on the soil nutrient dynamics of Rapa Nui has just begun. The initial results of our preliminary analyses provide intriguing insights into the changing and challenging environment of Rapa Nui, and suggest several avenues for future research. While we can not yet establish how soil nutrients varied over time, the low resin-P and Mehlich P values do indicate that Rapa Nui soils are currently quite poor. These low values are probably the result of the age of the volcanic substrates and natural processes of leaching. In these conditions horticultural and agricultural activities would further decrease nutrient levels and would not have been sustainable over extended periods of time without intensive practices. There is some archaeological and chemical evidence that people practiced innovative gardening techniques and that these might have enhanced soil nutrient levels. Even with these intensive activities the poor and declining soils of Rapa Nui would have created an extremely challenging environment and could have contributed to the decline of pre-contact society.

Our future work will clarify some of these relationships.

We will systematically sample nutrient levels of all the main lava flows on the island. This will include extensive spatial coverage of the various group and sub-group volcanics, but more importantly the excavation of trenches extending from the surface to bedrock to recover vertical soil samples. This will allow us to establish a temporal framework of nutrient dynamics on the island. We will also systematically sample soils within the different classes of agricultural features (boulder gardens; veneer surfaces; rock mulched areas; planting enclosures; pits) to determine if nutrient levels within these features were enhanced. Experimental laboratory procedures are being developed to evaluate the possible input of nutrients from weathering and crushed volcanic rock. In this way it will be possible to assess the impact that innovative agricultural adaptations had on dynamic soil nutrient levels, and the effect these processes had on pre-contact societal transformations.

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